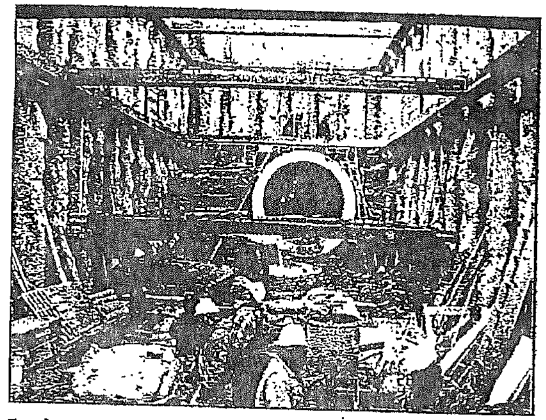
2006 MI-Award Project

Speedy effort fixes Macomb Interceptor giant sinkhole

Story adapted from the award application narrative



Replacement pipe installation, February 4, 2005

2006 MI-APWA award winning project

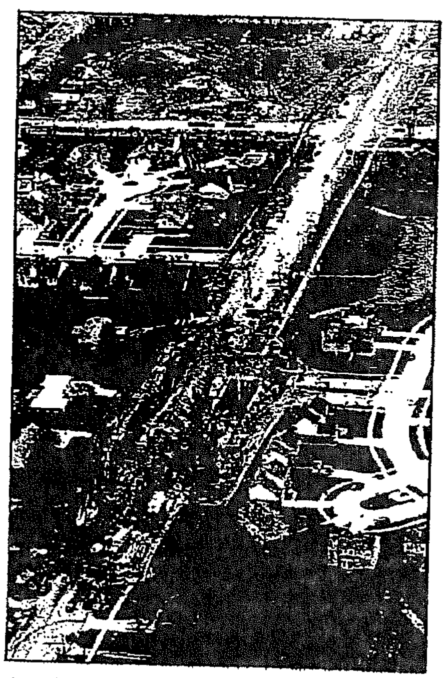
Category: Disaster or Emergency

Construction/Repair $10–$100 million

Managing Agency: Detroit Water and Sewerage Department

Contractor: Inland Waters Pollution Control, Inc.

Engineer: NTH Consultants, Ltd.



Aerial view shows extent of the project.

On Sunday morning, August 22, 2004, the City of Sterling Heights Police Department reported water on Fifteen Mile Road and a slight sinking of the pavement. The eight-inch water main was valved off; however, pavement near the water main continued to collapse and a failure of the Macomb Interceptor that lies approximately sixty feet below the pavement was suspected. This 11-foot diameter sewer under the jurisdiction of the Detroit Water and Sewer Department (DWSD) serves 600,000 residents and has a flow capacity of 30 to 60 million gallons per day. As more and more of the surrounding soil continued to fall into the interceptor and be carried to the Detroit Wastewater Treatment Plant, six homes on the south side of 15 Mile Road were evacuated as a safety precaution. The DWSD authorized Inland Waters Pollution Control, Inc. to develop a project team of engineers and contractors to stabilize and dewater the sink hole, with particular urgency along the existing homes that were evacuated and to install by pass piping and pumps to route the sewerage around the collapsed interceptor. Inland Waters was instructed to have all personnel work 24/7 to develop and implement a plan that would maintain sewer service while preventing damage to the nearby homes. Once the hole was stabilized and dewatered by the use of injection grouting, steel sheeting, and the installation of 13 dewatering wells 90-100 feet deep, the area was excavated to a depth of 35 feet and 228 caissons around the repair area were installed to a depth of 65 feet. Access shafts and bulkheads east and west of the repair area were installed near existing manholes to isolate the repair area so that repair crews could begin digging down to expose the interceptor.

To replace the damaged portion of the interceptor, the top portion of the collapsed interceptor was removed so that a concrete mud mat could be placed on top of the remaining crushed invert sections. Once the mud mat was in place, holes were drilled down into the remaining interceptor to totally fill every cavity left in the damaged section to form a solid support base. A steel and concrete cradle was then installed on top of the mud mat to support the new pipe sections. This additional support was installed and the new pipe was installed in line with the existing inverts both east and west of the repair area because the profile of the failed sewer sections was so severe that the existing gradient could be maintained.

The repair required an excavation 240 feet long and 40 feet wide to facilitate the installation of 23 pipe sections 11 feet in diameter and 8 feet in length. The real story in this repair, besides the engineering strategies utilized, was the schedule or timetable to completion that was required to satisfy the demands of the businesses in the area, the residents of Sterling Heights, DWSD, and

especially the homeowners on 15 Mile Road adjacent to construction.

The interceptor was in service on March 14, 2005 and 15 Mile Road was paved and open to the public on June 9, 2005.

Construction Schedule

2004

August 22: Leak in 8" water main detected and reported.

August 31: Pressure grouting inserted into 31 locations around the interceptor to stabilize the ground. Steel sheeting was placed on the south side of 15 Mile Road. Five dewatering wells are in place. Two 12-inch temporary sewage by pass lines are in place.

September 7: Two 36-inch bypass lines are installed; six dewatering are in service.

September 15: Two suction shafts east of the repair area and one discharge shaft west of the repair area are in place.

September 30: Two 36-inch sewage bypass lines are completed along with 12 dewatering wells.

October 15: The bulkhead east of the repair area was being installed.

October 22: To abate noise, electrical feeds have been installed for all equipment replacing diesel generators. Work continues on installing bulkheads.

October 29: The east bulkhead has been completed by the divers. The temporary gravel road on the north side of 15 Mile has been paved with asphalt for winter travel by the residents.

November 5: Crews began installing caissons around the repair area. The crews were scheduled 24/7 until the 228 caissons were in place.

November 12: The west bulkhead was in place and sand and sludge was being removed from the interceptor. The augers had drilled 39 caissons to date.

November 29: 92 caissons were in place. Crew had begun excavating down to the interceptor at the east end.

December 17: 158 caissons were in place. The excavation is now 120' x 40' x 35' deep.

December 29: 192 caissons were in place. 30 feet of the failed interceptor was exposed; 13 dewatering pumps were working.

January 14: Caisson installation was completed. 50 feet of mud mat was in place.

January 21: First replacement pipe was installed.

February 18: 23 replacement pipes (8 feet long, 11 feet in diameter) were installed and first layer of back fill was started.

March 11: Work was started to remove bulkheads. 14 dewatering wells were dismantled.

March 14: Interceptor was in service.

June 9: 15 Mile Road was paved and open to traffic.

The construction project enjoyed excellent weather. On the holidays of Thanksgiving, Christmas, and New Years Day, a 12–hour day shift was canceled.

Safety Performance

A health and safety officer was on site 24 hours each day. Confined space rescue equipment was on site at all times. A three-man confined space rescue team was in place when a sewer entry was scheduled and when the divers were employed to install the bulkheads.

Sewer gas was constantly vented at all open accesses to the interceptor. The entire site was fenced off, with guards posted 24/7 at each end of the project and at the intersecting streets.

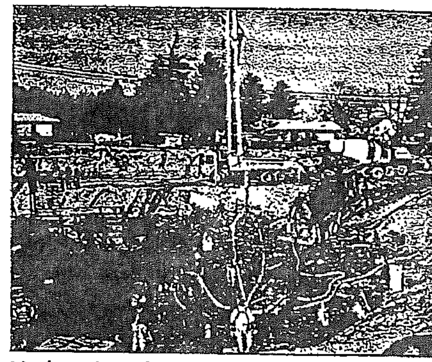
By putting safety first, no lost time accidents occurred during the project.

Community Relations

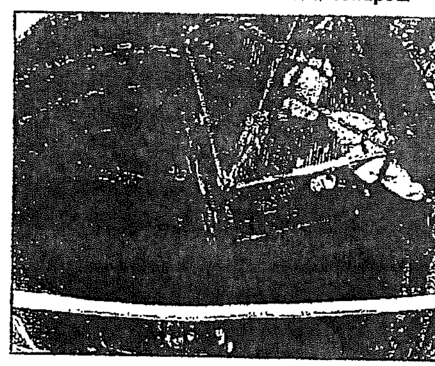
The City of Sterling Heights, the City of Fraser, and Clinton Township were involved from the start with their police and fire departments handling the evacuation of the affected homes and rerouting traffic. A phone hot line was set up to handle the concerns of residents and businesses.

All utilities were affected. The Detroit Edison Company, Consumers Power, two cable companies, and Michigan Bell were quickly on site to restore their services.

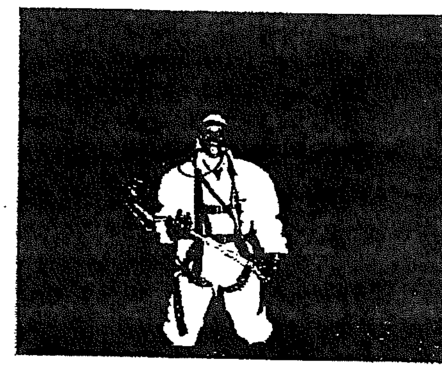
The concerns of the residents located adjacent to the expanding sinkhole were met



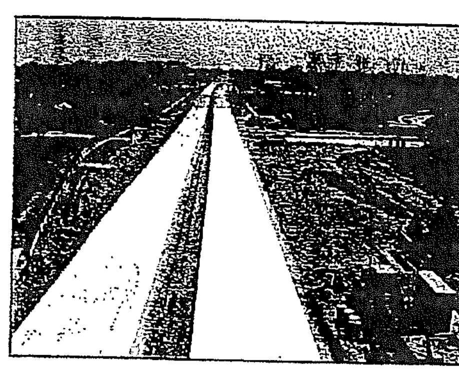
Mud mat installation and compaction grouting started within a week of the sewer collapse.



Diver duo is lowered into shaft.



Divers were critical players in the bulkhead installation. Working two at time, in two-hour shifts, up to 14 divers were on site to keep a 24/7 schedule. Most of the clearing work had to be done with "shovel technology".



Newly paved 15 Mile Road in May 2005.

with personal contact by the DWSD staff. Paved access roads were constructed so that all homes and businesses were accessible to the public.

The DWSD created a web site that presented a weekly progress update and was linked to Sterling Heights' site. DWSD also held periodic town meetings for residents.

Environmental Considerations

The immediate environmental concern was handling the upstream effluent to prevent contamination of the surrounding area and sewer overflows that would have caused basement flooding. An emergency bypass pumping system was installed and operating in four days.

Construction Techniques

The immediate need at the outset was to stabilize the soil around the interceptor and around the six homes that had to be evacuated. This was accomplished by "compaction grouting" and the installation of sheet piling where the sinkhole was encroaching towards the homes. Compaction grouting helped to stiffen the sandy soil to the point where the ground water would not carry it into the large void caused by the collapsed interceptor. With this grouting method, liquefied material is injected into the soil to create a cemented mass. Injection grouting was also employed on areas around the interceptor that were still moving. Injection points were installed by driving two-inch pipes down into the soil and pumping a mixture of sand, silt, and cement into the voids. Three injection passes insured that no further movement occurred.

To assist in soil stabilization a dewatering system was installed. It involved 12 deep wells ranging from 80 to 100 feet deep using multiple generators and high volume ground pumps. The dewatering wells were a critical component in getting access to the interceptor through excavation, and bringing the water table below the invert of the pipe.

The more permanent bypass system involved the construction of two shafts upstream of the collapse that housed two triple stage 30-inch and two triple stage 24-inch axial flow pumps that discharged into two 36-inch HDPE lines. Each triple stage unit contained three large impellers each driven by an individual hydraulic motor. This equipment was installed in the next four weeks and sufficiently handled the required sewerage volume.

Drilling the shafts, coordinating materials, and locating qualified divers were the major obstacles in this effort. The divers had to work in 35 feet of water where visibility was limited, and they needed to core into the existing pipe without damaging its integrity.

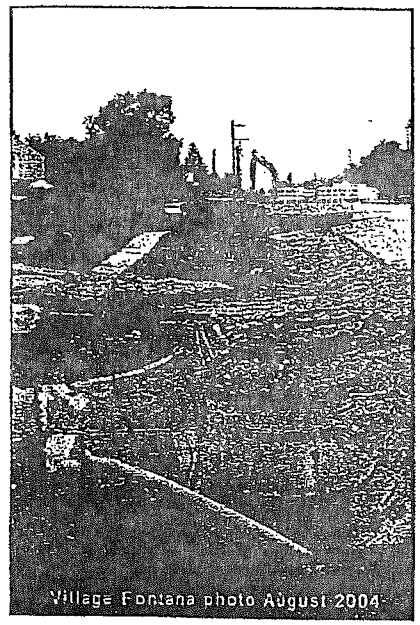
The existing pipe was poured in place, so divers needed to cut through the steel ribs and wood lagging installed during the original sewer construction before tackling the cast-in-place concrete lining. The divers were only permitted to work two-hour shifts. Up to 14 divers were employed at the site at one time to maintain the 24/7 operations.

The next task for the divers was installation of the bulkheads to isolate the damaged area of the interceptor. An earth retention system consisting of a total of 228 auger piles and then the bracing was installed as the excavation proceeded along the sinkhole and the damaged interceptor was uncovered. Reinforced precast concrete pipe replaced the existing poured in place concrete pipe.

Installation of the sheet piling near the homes was accomplished by auguring down 30 feet and placing the piling in the hole before using a pneumatic hairpin hammer to drive them down to resistance. This hammer was designed to minimize noise and vibration. The piling was set during the night and driven during the day.

Innovations in Technology

Once the new precast pipe was in place and the bulkheads removed, the 7,000 cubic yards of materials that washed down stream of the collapsed interceptor were removed. Inland Waters designed and implemented a "Hydro Sled" device that created a movable bulkhead within the pipe that held back the flow. A hydraulic weir located at the bottom of the sled allowed the effluent to charge upward creating a turbulence, thus causing the deposited materials to flow down stream in suspension where they were removed with a two stage 8-inch hydraulic pump and placed into a decanting trailer for disposal. Over 5,000 feet of the 11-foot diameter sewer was cleaned with the "Hydro Sled" method.



Village of Fontana view August 24, 2004.

Conclusion

The well-organized effort for this challenging project was successful in terms of enjoying community support, protecting the environment by staffing the project 24/7, and accomplishing the rehabilitation of the interceptor and opening 15 Mile Road and intersecting streets in a satisfactory time frame. The DWSD created an organized and efficient job site. All decisions were made in the field. All revisions were reviewed and approved right then and there, which required the DWSD engineering and construction staff to be on site every day. The communications between residents, officials, and contractors fostered a feeling of camaraderie that insured the successful completion of this project.

North American Tunneling 2006 – Ozdemir (ed.)

Emergency repair of Oakland-Macomb Interceptor collapse: A case history

V. Mercado, G. Fujita, & R. Shukla
Detroit Water and Sewerage Department

H.R. Price, K.M. Swaffar, & F.J. Klingler
NTH Consultants, Ltd

ABSTRACT: The Oakland Macomb Interceptor is an 11-foot diameter sanitary sewer that services approximately 200,000 people in Macomb County Michigan. The 62-foot deep monolithic concrete lined sewer lies directly below 15-Mile Road, which is a major traffic artery for the City of Sterling Heights, Michigan and surrounding area. On the morning of August 22, 2004, approximately 250-foot long by 130-foot wide interconnected sinkholes developed over the sewer, forcing the closure of the roadway and temporary evacuation of several adjacent homes. Further complicating matters, there were no redundant sewers to carry the 70,000 gallons per minute of peak flow from the service area. Within hours, the Detroit Water and Sewerage Department (owner and operator of the interceptor) mobilized a team of engineers and contractors to assess the situation, then design and construct temporary bypass facilities and permanent repairs. This team worked 24-hours per day, 7-days per week until the repair was substantially complete.

This paper will provide a discussion of innovative methods employed by the DWSD to stabilize the sinkhole, protect nearby homes, construct the emergency temporary bypass, and accomplish the permanent repairs. Specific technical challenges included: combined jet grouting and sheeting to stabilize the sinkhole; constructing "live-tap" shafts over the sewer; installation of short term and long term bypass pumping stations; and construction of the 200-foot long, 70-foot deep tunnel repair shaft. Logistical challenges included assembling a qualified team to accomplish the emergency project, coordinating with numerous affected municipal governments and regulators, and addressing the concerns of the media and public. The emergency repair was conducted over a period of about 10 months, with total cost of about $50 million.

1 BACKGROUND

1.1 *Original construction*

The existing interceptor sewer was constructed under DWSD Contract Number PCI-12A. Records from the original construction indicate that the 11-foot diameter sanitary sewer was constructed to service an area of approximately 55 square miles in the northeastern suburbs of Detroit, Michigan. This area consists of the communities of Mt. Clemens, Fraser, Clinton Township, Harrison Township, and the northeast portion of Sterling Heights.

The sewer was designed and constructed with an invert depth of approximately 60 feet below the ground surface in the section between Hayes and Moravian Roads. The sewer was constructed in-tunnel, using an open face rotating head tunnel boring machine under approximately 20 to 30 psi of compressed air. The tunnel liner generally consisted of a primary lining of W4x13 steel ribs at 4 feet on-center, with 4-inch thick wood lagging. The secondary (permanent) lining was constructed as cast-in-place monolithic (unreinforced) concrete. Contract No. PC-12A was completed in 1972.

1.2 *Ground conditions*

Ground conditions in the vicinity of the sinkhole consist of approximately 30 feet of stiff silty clay underlain by interbedded layers of compact to very compact silty sand, sand, and sandy gravel. The groundwater pressure head within the confined granular aquifer through which the sewer tunnel extends is at approximately 15 feet below ground surface, which corresponds to a head of about 45 feet at the level of the tunnel.

1.3 *Typical sewage flow condition*

The average dry weather flow through the interceptor is 50 cubic feet per second (cfs), with peak flows

during wet weather as high as 160 cfs. While there is no redundancy of the sewer and flow could not be re-directed around the collapsed area, theoretically the flow could be mostly throttled by the Garfield Gate, located approximately 3000 feet upstream. However, this would result in basement flooding and in a worse case scenario, overflow to the Clinton River, which was not allowed under any circumstances by the environmental regulating agencies. Further, the Garfield Gate was located upstream of the Fraser Sewer connection, that directs about 5 cfs of dry weather flow to the Oakland Macomb Interceptor immediately upstream of the collapsed area.

1.4 *History of sewer collapse in the area*

In July 1978, a failure of the Oakland Macomb Interceptor sewer occurred within the intersection of 15 Mile and Hayes Roads, as a result of adjacent construction activities by a third party contractor hired by a local municipality. The center of that failure was located approximately 900 feet east of the center of the present failure. The repair of the failed sewer involved construction of a bypass pumping station and above-ground force main bypass, followed by construction of a mined 8-foot diameter bypass tunnel around the collapsed area. The repair was performed in stages, and required about 4 years to complete.

2 SHORT TERM STABILIZATION AND FLOW CONTROL

Following the August 22, 2004 discovery of the developing depression along 15 Mile Road, the DWSD mobilized an emergency response contractor as well as geotechnical, structural, and hydraulics engineers to assess and stabilize the situation. The project team assembled by DWSD included Inland Waters for overall project management/administration, closed circuit television surveys, sewer cleaning and construction safety; L.D'Agostini & Sons Contractors (LDS) for construction support; and NTH Consultants, Ltd. for engineering support. LDS and NTH both retained individual subcontractors or subconsultants to provide the expertise and manpower necessary to implement the repairs. Subcontractors for LDS included Mersino Dewatering, Rotor Electric, O'Laughlin Construction, Thompson Pump Midwest, Spartan Specialties, and Great Lakes Diving and Salvage. NTH was supported by subconsultants Spalding DeDecker Associates, Lakeshore Engineering, Superior Engineering, Multi-Solutions Technologies, and Malcolm Pirnie, Inc.

2.1 *Emergency (short term) flow control*

Because of uncertainties regarding the ability of the underlying Interceptor to continue carrying its normal sewage flows, it was recognized that several work tasks needed to be performed immediately and concurrently. LDS and their subcontractor, Mersino Dewatering, immediately started work on emergency flow control measures. These measures consisted of installing pumps and multiple discharge lines at the Clinton/Fraser Connection manhole and an adjacent upstream manhole on the Fraser system. This system was designed to maintain the level of sewage in the Interceptor below approximately Elevation 585, to minimize the risk of basement flooding upstream of the sinkhole. To improve the system effectiveness, a 24-inch diameter pump was subsequently installed in the manhole located upstream of the collapse to the sewer. Flows from this pump were directed into a surface discharge line and conveyed to the discharge shaft located downstream of the sinkhole.

2.2 *Dewatering*

The inflow of groundwater and soil fines into the sewer as a result of the break was of concern to all parties. Within hours, a dewatering plan developed and well installation began. The initial dewatering plan consisted of 10 dewatering wells, 8-inch diameter, positioned at a nominal 100-foot spacing around the perimeter of the sinkhole. In order to monitor the effectiveness of the dewatering measures, a series of observation wells were also constructed.

As a result of underground obstructions and further refined repair strategies, a total of 13 dewatering wells were eventually installed around the perimeter of the sinkhole. These wells were designated as Dewatering Wells 1 through 5, 5A, and 6 through 12.

2.3 *Short term stabilization using sheet piling*

In combination with the dewatering, a line of steel sheeting was designed and installed to provide short term stabilization of the sinkhole along the south side adjacent to residences. The sheet pile stabilization method was chosen because it could be installed quickly and would be effective in the short term before a more substantial jet grouting operation could be undertaken.

The sheet pile wall was designed using 50-foot long PZ-38 steel sheeting, and installed by the E.C. Korneffel Co. under subcontract to LDS. To minimize vibrations associated with installing the sheet piles, the sheeting line was initially predrilled to a depth of 30-feet in immediate advance of the pile driving. Sheet piles were driven using a combination of impact and vibratory hammers. The vibrations resulting from installation of the sheet piles were monitored throughout the driving process, and were generally well below the U.S. Bureau of Mines residential damage criteria of 2 inches per second.

ized that several work
l immediately and con-
subcontractor, Mersino
ted work on emergency
e measures consisted of
e discharge lines at the
anhole and an adjacent
aser system. This sys-
l the level of sewage in
nately Elevation 585, to
al flooding upstream of
system effectiveness, a
ubsequently installed in
a of the collapse to the
were directed into a sur-
ed to the discharge shaft
khole.

l soil fines into the sewer
f concern to all parties.
lan developed and well
l dewatering plan con-
, 8-inch diameter, posi-
ot spacing around the
n order to monitor the
g measures, a series of
nstructed.
obstructions and further
l of 13 dewatering wells
nd the perimeter of the
signated as Dewatering
hrough 12.

using sheet piling

atering, a line of steel
stalled to provide short
khole along the south
he sheet pile stabiliza-
ise it could be installed
in the short term before-
ng operation could be

lesigned using 50-foot
d installed by the E.C.
ct to LDS. To minimize
talling the sheet piles,
y predrilled to a depth
nce of the pile driving.
a combination of impact
ibrations resulting from
were monitored through-
re generally well below
dential damage criteria

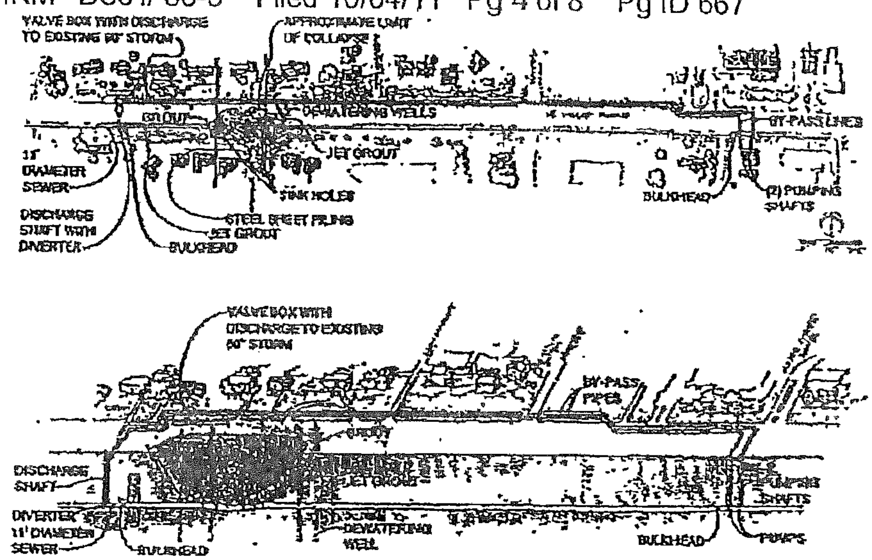


Figure 1. Plan and profile of sinkhole and pumping bypass.

2.4 *Jet grouting*

In order to provide a longer term stabilization, the project team utilized the jet grouting process to create a barrier near the sewer pipe; to minimize the flow of soil and groundwater into the sewer; and limit any further collapse of the sewer. Hayward Baker constructed two jet grout walls under subcontract to LDS. This process involved neat cement grout injected and mixed into the silty sand soils below a depth of about 30 feet at high pressure to form soil-cement columns. Interconnected columns were formed to provide groundwater cutoff and soil retention.

Injection pressures between 2500 and 4500 psi were used during the application. The jet grout walls were oriented perpendicular to and centered on the longitudinal axis of the Romeo Arm Sewer, approximately 55 feet outside the sinkhole limits on the east and west.

2.5 *Compaction grouting*

Compaction grouting was also conducted in an attempt to densify and stabilize the soils around the sewer pipe until dewatering measures could be effectively implemented to lower the groundwater table. This method consisted of the injection of a stiff cement-based grout (a mixture of sand, cement, topsoil and water) into the soil at selected intervals. The grout was placed at high pressure to form an expanding cylinder at its point of injection, thereby densifying adjacent soils.

The grout holes for the compaction grouting were battered in an attempt to provide densification under the haunches of the sewer pipe. Two rings of compaction grout holes were placed around the two main depressions. The outside ring circumscribed the depressions, while the second ring was located in the depressions approximately 6 feet inside of the initial ring.

3 TEMPORARY LONG TERM BYPASS

In order to effect repairs to the damaged sewer to make it again operational, it was recognized that a temporary long term bypass around the sinkhole area would have to be established to handle the normal dry and wet-weather flow volumes within the sewer for the duration of the repair. It was expected that the permanent repair would take many months, and potentially more than one year.

Based on the range of flow rates anticipated (50 cfs dry weather, 100 cfs 1-year frequency wet weather, and 150 cfs peak wet weather), DWSD and the project team decided to construct pumping capacity at the site that could handle 100 cfs of flow.

A concept for the temporary bypass was developed that involved two 10-foot diameter in-line pumping shafts, two 36 inch above-ground (or near-grade) HDPE force main pipes, and a 10-foot diameter in-line discharge shaft. A general configuration of the long term temporary bypass pumping is shown on Figure 1.

During construction of the long term temporary pumping, flow through the collapsed/settled section of sewer continued, although the upstream end of the sewer was backed up and surcharged up to 30 feet due to the collapse/settlement and obstruction. This unavoidable condition posed a constant threat of basement flooding, although such flooding was avoided through the duration of the long term temporary bypass construction.

3.1 *Temporary bypass pumping shafts*

To maintain access to the eastern end of the 96-inch diameter bypass constructed in the 1980's (and in particular maintain access to existing manhole shafts in this area), upstream pump stations needed to be located east of the former repair area. In addition, it was desired to keep the new pump stations to the west of the abandoned pump station from the 1978 failure.

Based on the existing site conditions, an area east of the intersection of 15 Mile Road and Eberlein Drive (about 2000 feet upstream of the collapsed area) appeared to be the most desirable location for the temporary bypass pump stations. These locations corresponded to PCI-12A Stations 85 + 45 and 85 + 95.

The two pumping shafts were constructed as live-tap shafts of the upstream sewer tunnel. The construction procedure involved auger drilling and installation of steel casing to the top of the sewer; followed by excavation of the soil above the tunnel liner; then removal of the primary lining. Due to concern about the stability of the surcharged monolithic liner, at least 20 feet of water was maintained in the shafts during construction, and divers were required to excavate the last several feet and remove the steel rib and wood lagging primary lining. Reinforced concrete tremie plugs were then placed, and 60-inch cores were cut through the plugs and secondary lining.

3.2 *Discharge shafts*

With respect to a discharge shaft, it was initially thought that an abandoned shaft from the previous repairs might be used for access to the sewer. However, exploratory efforts to locate the shaft concluded that it had been completely removed following completion of the 1978 repair efforts. Therefore, it was decided to construct the discharge shaft approximately 100 feet downstream of the manhole located to the west of the sinkhole. This location was selected so that the existing manhole could be used to provide access to the sewer downstream of the present sinkhole.

The discharge shaft was constructed in a similar manner as the pumping shafts, except that a steel can diverter was placed at the bottom of the shaft to direct flow downstream during the permanent repair period.

3.3 *Long term temporary pumping*

Several types of pumps were considered for the project, including Flygt pumps and hydraulic pumps manufactured by MWI of Florida. Evaluations by the project team determined that, in order to achieve the required capacity, 3 pump shafts with two pumps each would be required to house the Flygt pumps, while only two pump shafts with two pumps each would be required for the MWI pumps. Ultimately, the MWI pumps were selected to minimize the number of penetrations through the sewer liner as well as minimize the time required to begin pumping. The pumps were provided with both electric and diesel power units. In addition, spare 30-inch and 24-inch pumps were provided in case the in-service pumps needed to be removed for repairs.

3.4 *Force main piping*

To convey the wastewater from the two pump shafts to the discharge location as well as to provide redundancy in the system, it was decided to install twin 36-inch diameter HDPE conveyance pipes on the ground surface along the north side of 15 Mile Road. The connections between the pump and these pipes were configured so that discharge from the pumps could be diverted to either of the lines, should repairs to one of the discharge lines be required. HDPE pipes were selected because of their relative flexibility and ease of construction. At the Discharge shaft, a 90-degree bend was provided that redirected the flow down the discharge shaft and into the steel diverter installed at the bottom of the shaft. To prevent siphoning, the 42-inch pipe was not physically connected to the diffuser.

The entire long term temporary bypass system (including the pump stations, bypass pipelines and the discharge shaft), was completed and functional by September 30, 2005, about 5 weeks after the initial sewer tunnel collapse.

4 PERMANENT REPAIR

While emergency and temporary measures were being undertaken, several solutions to permanently repair the Interceptor were evaluated, including the construction of a new 11-foot diameter tunnel from the East Access Shaft to beyond the present sinkhole and the extension of the existing 8-foot inside diameter by-pass. Ultimately, it was concluded that the most expedient and cost effective solution was to construct a recovery shaft encompassing the physical limits of the damaged section of sewer, remove the damaged section, install new piping, and backfill the shaft to ground surface. Key activities/features for this concept included constructing bulkheads to isolate the damaged portion of the sewer; dewatering the area to a level

umping

ere considered for the
ps and hydraulic pumps
vide. Evaluations by the
:, in order to achieve the
ifts with two pumps each
the Flygt pumps, while
/o pumps each would be
s. Ultimately, the MWI
nize the number of pen-
ner as well as minimize
nping. The pumps were
and diesel power units.
id 24-inch pumps were
ce pumps needed to be

n the two pump shafts to
is to provide redundancy
l to install twin 36-inch
: pipes on the ground
15 Mile Road. The con-
id these pipes were con-
m the pumps could be
s, should repairs to one
ired. HDPE pipes were
ve flexibility and ease of
: shaft, a 90-degree bend
the flow down the dis-
. diverter installed at the
d siphoning, the 42-inch
cted to the diffuser.
nporary bypass system
s, bypass pipelines and
pleted and functional by
i weeks after the initial

try measures were being
o permanently repair the
duding the construction
nel from the East Access
sinkhole and the exten-
tside diameter by-pass.
that the most expedi-
on was to construct a
: the physical limits of
r, remove the damaged
nd backfill the shaft to
Features for this concept
ads to isolate the dam-
atering the area to a level

of at least 5 feet below the bottom of the replacement pipe; precutting the area to approximately Elevation 594, constructing a braced excavation; removing the damaged pipe; installing a new pipe; backfilling; and ultimately restoring the pavement and affected area to pre-sinkhole conditions.

4.1 *Construction of bulkheads*

Following the installation of the long term temporary bypass pumping system, work was started on the installation of segmental steel bulkheads. These prefabricated bulkheads were to be installed both upstream and downstream of the damaged area to isolate it from the adjacent active sewer. The bulkheads were designed to hold back 60 feet of hydrostatic pressure.

To prepare the sewer for construction of the steel bulkheads, an attempt was initially made to construct temporary dams made with sand bags. However, this method was unsuccessful, and alternative methods were evaluated. After reviewing various bladders and commercially available metal and rubber sealing plates, grout filled geobags were selected because of their availability and ease of installation. The geobags ranged from 4 feet by 4 feet by 1-foot thick to 8 feet by 11 feet by 1-foot. The bags were positioned by divers and filled with a cementitious grout mixture. Once the geobags were installed, divers supported by laborers under supplied air maintained the individual work areas as dry as possible to facilitate the work. The eastern segmental steel bulkhead was completed on October 26, 2004.

Once the eastern segmental steel bulkhead was completed, the broken concrete slabs then existing in the sinkholes were removed and the sinkholes were filled to the pre-cut elevation, Elevation 594. To mitigate the potential collapse of the existing sewer during the installation of the recovery shaft walls, it was filled with a cement/fly ash grout mixture. A series of probes were then drilled perpendicular to the longitudinal axis of the sewer along the sewer alignment to define the north and south limits of the sewer in the sinkhole area. Based on the data from these probes, the final wall alignments for the recovery shaft were selected. During the preparation of the recovery shaft area, an 18-foot diameter shaft was constructed around the 4-foot manhole at Station 65+98. The purpose of this shaft was to facilitate the installation of the west segmental steel bulkhead by providing improved access. Following the completion of the new shaft, the west segmental bulkhead was completed on November 14, 2004.

4.2 *Recovery shaft*

Based on an evaluation of subsurface conditions, the proximity of the adjacent homes and the need to work 24 hours a day for an extended period of time, it was determined that a tangent drilled pier concrete wall would be the most suitable wall system for the project.

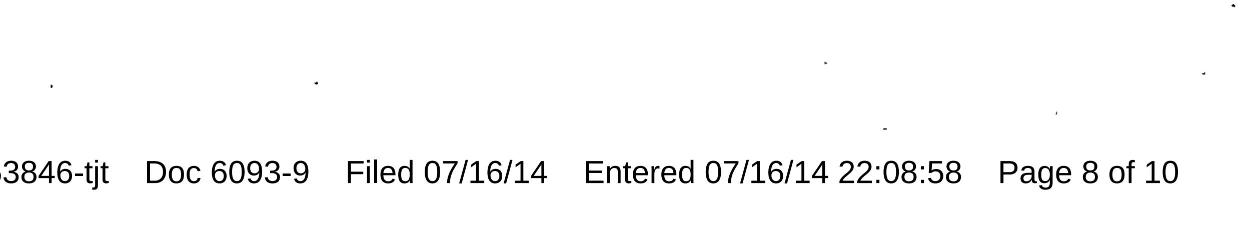
The design of the tangent wall consisted of 228 concrete piers installed in two staggered rows forming a continuous wall. To support the walls, internal steel bracing was constructed at Elevations 588, 575, 562 and 544. The internal bracing system also included a concrete mud mat at the bottom of the excavation, Elevation 544. A total of 114 piers were reinforced with steel wide flange sections in the row of piers forming the interior face of the wall. The 114 tangent piers that formed the outside of the wall were constructed of plain (unreinforced) concrete. The tips of the piers were generally 64 feet below the precut elevation (Elevation 530). The exceptions to this occurred where the wall crossed the existing sewer lines (both active and abandoned) and at the crossing of the former terminal shaft for PCI-37. The installation of the drilled piers commenced on October 31, 2004 and was completed on January 8, 2005.

The excavation of the recovery shaft and the installation of the interior bracing were started on November 24, 2004 and completed 100 days later on March 4, 2005. The excavation was generally accomplished in stages that ranged in depth from about 10 feet to about 15 feet. In general, the excavation stages extended approximately 3 feet below the individual bracing levels to facilitate their installation. The excavation of the next stage did not commence until the steel bracing had been welded in place.

During the excavation, a temporary level of bracing (jump set) was installed at elevation 554 until the concrete mud mat could be installed at the bottom of the shaft. On the east end of the shaft, the invert of the sunken PCI-12A tunnel extended approximately 4 feet below the bottom of the excavation. At that location, it was determined that the complete removal of the tunnel liner could not be accomplished without impacting the stability of the excavation support system. In order to address this situation, the excavation was performed in small sections to take advantage of three-dimensional effects. Once the installation of the mud mat was completed, grouting of the underlying soils was performed to densify and stabilize any loose soils and fill any voids that might still exist. At the completion of the grouting, a series of 5 borings were drilled through the mud mat to verify the effectiveness of the grouting program.

4.3 *Installation of replacement sewer pipe*

The replacement sewer within the recovery shaft was designed as an 11-foot inside diameter pipe meeting the requirements of ASTM C-76 Class V. The pipe was coated with a cementitious mortar to improve the chemical resistance of the pipe to hydrogen sulfide attack. In conjunction with the installation of the replacement pipe, reinforced concrete closure sections



were cast on both ends of the replacement pipe. The closure sections extended over both the new pipe and the existing pipe. Hydrophilic water stops were provided at both of the closure sections. The concrete for both closures included the previously used proprietary admixture to reduce the permeability of the concrete and to improve the resistance of the concrete to hydrogen sulfide gas. The placement of the concrete for the closure represents the beginning and the end of the concrete cradle installation. The east closure was placed on January 15, 2005 and the west closure was placed on February 12, 2005.

In order to support the imposed loads from the overburden soils, the pipe was supported on a reinforced concrete cradle that extended to approximately the lower quarter point of the pipe sections, consistent with American Concrete Pipe Associations Class A Bedding. In order to facilitate the installation of the pipe and the reinforcing steel for the cradle, the pipe sections were supported on steel beams. The pipe sections were banded to the steel supports to prevent them from floating during the installation of the cradle. The initial cradle pour was on January 15, 2005. The final cradle pour was on February 12, 2005.

The area from the top of the concrete cradle to a level 18-inches above the crown of the pipe was filled with a flowable fill material. The initial placement of the flowable fill was on February 3, 2005 and the final placement was on February 14, 2005. The area from the top of the flowable fill to the preset elevation was backfilled with granular fill material.

When the fill material was at approximately elevation 590, the Sterling Heights sanitary sewer was reconstructed and gravity flow was restored. In addition, the removal of the segmental steel bulkheads and their associated geobag dams was commenced. The segmental bulkheads and their associated geobag dams were removed between February 23, 2005 and March 12, 2005. At the same time, pumps and the diverter were removed from the pumping shafts and the discharge shafts, respectively.

Following backfilling of the area to approximately the original grade, restoration of the site commenced. Access shafts were constructed out of the former pump shafts, the sinkhole manhole, the 18-foot diameter shaft, and the discharge shaft. In general, these access shafts consisted of precast manhole sections set on a concrete collar cast over the top of the sewer. At the ground surface, these access shafts were finished with flat slab covers approximately 12-inches below the ground surface elevations at the individual shaft locations. The purpose of these shafts is to facilitate DWSD's future maintenance operations.

4.4 *Resumption of flow in restored sewer*

After the repairs to the sewer had been completed, the bulkheads removed, the sewer cleaned to approximately Station 63+99 (downstream of the sinkhole), and the recovery shaft excavation backfilled to approximately Elevation 590, pumping from the upstream pumping stations was discontinued and wastewater was again allowed to flow through the sewer. Resumption of flow occurred on March 14, 2005.

4.5 *Cleaning sewer*

Failure of the sewer pipe resulted in the deposition of soils, sludge and debris in the sewer both upstream and downstream of the sinkhole area. In order to bring the sewer to full capacity, a program was initiated to remove the deposits from the sewer. Within the section encompassing the 8-foot diameter pipe, the PCI-37 terminal shaft, the recovery shaft, and the 18-foot diameter access shaft, the deposits were removed by hand excavation, mechanical excavation and vacuum trucks.

As a result of the failure, significant deposits of sludge and soils also existed between the 18-foot diameter shaft and the Corridor Interceptor. These materials could not be removed by similar methods because of the large distance between manholes in conjunction with approximately 5 feet of flow in the sewer. The spacing precluded the use of cables and buckets, while the flow depth precluded the use of tracked, wheel or skid steer machines. Further, the large 11-foot inside diameter of the sewer precluded the use of jetting as a viable technique. Based on evaluations by both NTH and Inland Waters, it was concluded that, for these conditions, deposits could be best removed using a portable dam with an underflow weir, a procedure developed and patented by Inland Waters and marketed under the name Hydrosled.

Subsequent to the resumption of flow in the interceptor sewer, the Hydrosled was used to clean the sewer working to the west from the 11-foot diameter access shaft. With this procedure, sediments were washed from the invert of the sewer into suspension. As the flowing wastewater transported the suspended materials downstream, the larger particles dropped from suspension first, followed by sand size particles, and then sludge and other fines. A dredge pump was positioned downstream of the Hydrosled to intercept and remove the suspended materials.

The amount of material removed by the dredge pump increased as the Hydrosled approached within roughly 600 feet of the dredge pump. Initially the materials tended to be sand sized particles. As the Hydrosled approached the dredge pump, increasing amounts of gravel sized particles were removed. The dredge material was lifted to the surface where the soil size particles were allowed to settle. Materials finer than sand sizes that would not settle out of suspension in a relatively short time were discharged back into

) (downstream of the haft excavation back- on 590, pumping from ms was discontinued owed to flow through e occurred on March

ed in the deposition of sewer both upstream area. In order to bring gram was initiated to wer. Within the section eter pipe, the PCI-37 haft, and the 18-foot sits were removed by cavation and vacuum

ignificant deposits of veen the 18-foot diam- eptor. These materials ilar methods because manholes in conjunc- of flow in the sewer. of cables and back- led the use of tracked, . Further, the large wer precluded the use Based on evaluations it was concluded that, ould be best removed nderflow weir, a pro- by Inland Waters and sled.

a of flow in the inter- as used to clean the n the 11-foot diame- dure, sediments were ower into suspension. ported the suspended ter particles dropped by sand size particles. . A dredge pump was lydrosled to intercept rials.

noved by the dredge ed approached within s pump. Initially the zed particles. As the lge pump, increasing s were removed. The surface where the soil ettle. Materials finer ttle out of suspension discharged back into the sewer together with the water removed with the dredge material. The materials removed by the dredge pump were trucked to a landfill for disposal. The sled advancement is a direct function of the water level within the sewer. The sled advance ranged from 15 feet to 80 feet; in general the advancement was approximately 50 feet per day. The sewer was cleaned from the new 11-foot Diameter Access Structure at Station 65+99 to the manhole at Station 18+49. The sewer was not cleaned from Station 18+49 to the Edison Corridor.

4.6 *Restoration of utilities, roadway and landscaping*

After resumption of flow in the sewer, construction activities to restore near-surface features were implemented. These included backfilling the recovery shaft excavation to pavement subgrade elevation; removing pumping and discharge equipment and bypass pipes; restoring all utilities; construction of the roadway pavement, and restoring landscaping and appurtenant items. When the road was re-opened to traffic on June 9, 2005, the site was completed restored and all traces of the sinkholes and resulting destruction were gone. Over a period of 298 days, a dedicated team of DWSD, its contractors and consultants executed nearly $50 million of construction, prevented any damage to the environment, and completed a repair program that on August 22, 2004 was expected to take 18 to 24 months to complete.